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A Sequential Procedure for Testing Unit Roots in the Presence of Structural Break in Time Series Data: An application to Quarterly Data in Nepal, 1970-2003

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Keywords

Sequential, Procedure, for, Testing, Unit, Roots, Presence, Structural, Break, Time, Series, Data, application, Quarterly, Data, Nepal, 1970, 2003

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A SEQUENTIAL PROCEDURE FOR TESTING UNIT ROOTS IN THE PRESENCE OF STRUCTURAL BREAK IN TIME SERIES DATA: AN APPLICATION TO QUARTERLY DATA IN NEPAL, 1970-2003

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Abstract

Testing for unit roots has special significance in terms of both economic theory and the interpretation of estimation results. As there are several methods available, researchers face method selection problem while conducting the unit root test on time series data in the presence of structural break. This paper proposes a sequential search procedure to determine the best test method for each time series. Different test methods or models may be appropriate for different time series. Therefore, instead of sticking to one particular test method for all the time series under consideration, selection of a set of mixed methods is recommended for obtaining better results.

Key Words: Time Series, Stationarity, Unit Root Test, Structural Break, Sequential Procedure

1. Introduction

Most empirical research deal with time series data. The long-term relationships between various time series and the pattern of effect of one variable on another variable are analysed. For this purpose cointegration and causality tests are commonly used. Prior to conducting the cointegration or causality tests, it is essential to check each time series for stationarity. If a time series is non-stationary, the

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regression analysis done in a traditional way will produce spurious results. Therefore, in order to examine non-stationarity of the time-series, the unit root test is conducted first.

This paper discusses the practical problems faced by the researchers while selecting the method of unit root test, and proposes a sequential test procedure in order to deal with such problems. In section 1, the concept of stationarity and non-stationarity of the time series are briefly discussed. Section 2 reviews some of the prominent unit root test methods that are available. In section 3, we propose a Hendry-type general-to-specific-search strategy for obtaining a parsimonious representation of the unit root test. In section 4, the problems faced in unit root test and the appropriateness of sequential test procedure are demonstrated by an example. Finally, the concluding remarks are presented in section 5.

2. Stationarity and Non-stationarity of Time Series

A time series is considered to be stationary if its mean and variance are independent of time. If the time series is non-stationary, i.e., having a mean and/or variance changing over time, it is said to have a unit root. Therefore, the stationarity of a time series is examined by conducting the unit root test. A non-stationary time series can be converted into a stationary time series by differencing. If a time series becomes stationary after differencing one time, then the time series is said to be integrated of order one and denoted by I(1). Similarly, if a time series has to be differenced d times to make it stationary, then it is called integrated of order d and written as I(d). As the stationary time series needs not to be differenced, it is denoted by I(0).

3. Unit Root Test Methods[1]

There are several methods available for conducting unit root test. This section briefly discusses these methods and models. Dickey-Fuller (DF), Augmented Dickey-Fuller (ADF), and Phillips-Perron

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[1] The notations used in equations 1-18 are the same as in the original papers.

(PP) test methods[2] are commonly used to examine the stationarity of a time series. The Dickey-Fuller (DF) model is as follows:

$$y_t \quad \mu \quad \alpha y_{t-1} \quad e_t \qquad (1)$$

Where ? is an intercept and e_t is a white noise. In this model, the null hypothesis is ? = 1 (non-stationary series) against the alternative hypothesis of $\alpha \quad 1$ (stationary series).

The error term in DF test might be serially correlated. The possibility of such serial correlation is eliminated in the following Augmented Dickey-Fuller model:

$$\ni y_t \quad \mu \quad \delta y_{t-1} \quad \int_{i\ 1}^{k} \beta_i \ni y_{t\ i} \quad e_t \qquad (2)$$

where, $\delta \quad \alpha \quad 1$

The null hypothesis of ADF is ? = 0 against the alternative hypothesis of ? < 0. Non-rejection of the null hypothesis implies that the time series is non-stationary whereas rejection means the time series is stationary. Phillips and Perron (PP) have suggested a non-parametric test as an alternative to the ADF test. Although the ADF test has been reported to be more reliable than the PP test, the problem of size distortion and low power of test make both these tests less useful (Maddala and Kim, 2003).

A Single Structural Break[3] in the Data Known a priori

Structural break can create difficulties in determining whether a stochastic process is stationary or not. Perron (1989) showed that in the presence of a structural break in time series, many perceived non-stationary series were in fact stationary. Perron (1989) re-examined Nelson and Plosser (1982) data and found that 11 of the 14 important US macroeconomic variables were stationary when known

[2] These were the prominent methods for conducting the unit root test prior to Perron's (1989) paper.

[3] Examples of structural break can be regime change, change in policy direction, external shocks, war etc. that may affect economic time series.

exogenous structural break is included[4]. Perron (1989) allows for a one time structural change occurring at a time T_B ($1 < T_B < T$), where T is the number of observations.

The following models were developed by Perron (1989) for three different cases:

Null Hypothesis:

Model (A) $y_t \quad \mu \quad dD(TB)_t \quad y_{t\ 1} \quad e_t$ (3)

Model (B) $y_t \quad \mu_1 \quad y_{t\ 1} \quad (\mu_2 \quad \mu_1)DU_t \quad e_t$ (4)

Model (C) $y_t \quad \mu_1 \quad y_{t\ 1} \quad dD(TB)_t \quad (\mu_2 \quad \mu_1)DU_t \quad e_t$ (5)

where $D(TB)_t = 1$ if $t = T_B + 1$, 0 otherwise, and
$DU_t = 1$ if $t > T_B$, 0 otherwise.

Alternative Hypothesis:

Model (A) $y_t \quad \mu_1 \quad \beta t \quad (\mu_2 \quad \mu_1)DU_t \quad e_t$ (6)

Model (B) $y_t \quad \mu \quad \beta_1 t \quad (\beta_2 \quad \beta_1)DT_t^* \quad e_t$ (7)

Model (C) $y_t \quad \mu_1 \quad \beta_1 t \quad (\mu_2 \quad \mu_1)DU_t \quad (\beta_2 \quad \beta_1)DT_t \quad e_t$ (8)

where $DT_t^* = t - T_B$, if $t > T_B$, and 0 otherwise.

Model A permits an exogenous change in the level of the series whereas Model B permits an exogenous change in the rate of growth. Model C allows change in both. Perron (1989) models include one known structural break. These models cannot be applied where such breaks are unknown. Therefore, this procedure is criticised for assuming known break date which raises the problem of pre-testing and data-mining regarding the choice of the break date (Maddala and Kim, 2003). Further, the choice of the break date can be viewed as being correlated with the data.

Presence of a Single Break Date Which is Unknown

Despite the limitations of Perron (1989) models, they form the foundation of subsequent studies that we are going to discuss. Zivot and Andrews (1992), Perron and Vogelsang (1992), and Perron

[4] However, subsequent studies using endogenous breaks have countered this finding with Zivot and Andrews (1992) concluding that 7 of these 11 variables are in fact non-stationary.

(1997) among others have developed unit root test methods which include one unknown structural break.

Zivot and Andrews (1992) models are as follows:
Model with Intercept

$$y_t \quad \hat{\mu}^A \quad \hat{\theta}^A DU_t(\hat{\lambda}) \quad \hat{\beta}^A t \quad \hat{\alpha}^A y_{t-1} \quad \sum_{j=1}^{k} \hat{c}_j^A \Delta y_{t-j} \quad \hat{e}_t \tag{9}$$

Model with Trend

$$y_t \quad \hat{\mu}^B \quad \hat{\beta}^B t \quad \hat{\gamma}^B DT_t^*(\hat{\lambda}) \quad \hat{\alpha}^B y_{t-1} \quad \sum_{j=1}^{k} \hat{c}_j^B \Delta y_{t-j} \quad \hat{e}_t \tag{10}$$

Model with Both Intercept and Trend

$$y_t \quad \hat{\mu}^C \quad \hat{\theta}^C DU_t(\hat{\lambda}) \quad \hat{\beta}^C t \quad \hat{\gamma}^C DT_t^*(\hat{\lambda}) \quad \hat{\alpha}^C y_{t-1} \quad \sum_{j=1}^{k} \hat{c}_j^C \Delta y_{t-j} \quad \hat{e}_t \tag{11}$$

where, $DU_t(\lambda) = 1$ if $t > T\lambda$, 0 otherwise;

$DT_t^*(\lambda) \quad t \quad T\lambda$ if $t\ !\ T\lambda$, 0 otherwise.

The above models are based on the Perron (1989) models. However, these modified models do not include DT_b.

On the other hand, Perron and Vogelsang (1992) include DT_b but exclude t in their models. Perron and Vogelsang (1992) models are given below:
Innovational Outlier Model (IOM)

$$y_t \quad \mu \quad \delta DU_t \quad \theta D(T_b)_t \quad \alpha y_{t-1} \quad \sum_{i=1}^{k} c_i \Delta y_{t-i} \quad e_t \tag{12}$$

Additive Outlier Model (AOM) – Two Steps

$$y_t \quad \mu \quad \delta DU_t \quad \tilde{y}_t \tag{13}$$

and

$$\tilde{y}_t \quad \sum_{i=0}^{k} w_i D(T_b)_{t-i} \quad \alpha \tilde{y}_{t-1} \quad \sum_{i=1}^{k} c_i \Delta \tilde{y}_{t-i} \quad e_t \tag{14}$$

$\tilde{y}$ in the above equations represents a detrended series y.

Perron (1997) includes both t (time trend) and DT_b (time at which structural change occurs) in his Innovational Outlier (IO1 and IO2) and Additive Outlier (AO) models.

Innovational Outlier Model allowing one time change in intercept only (IO1):

$$y_t \quad \mu \quad \theta DU_t \quad \beta t \quad \delta D(T_b)_t \quad \alpha y_{t\ 1} \quad \underset{i\ 1}{\overset{k}{f}} c_i \ni y_{t\ i} \quad e_t \tag{15}$$

Innovational Outlier Model allowing one time change in both intercept and slope (IO2):

$$y_t \quad \mu \quad \theta DU_t \quad \beta t \quad \gamma DT_t \quad \delta D(T_b)_t \quad \alpha y_{t\ 1} \quad \underset{i\ 1}{\overset{k}{f}} c_i \ni y_{t\ i} \quad e_t \tag{16}$$

Additive Outlier Model allowing one time change in slope (AO):

$$y_t \quad \mu \quad \beta t \quad \delta DT_t^* \quad \tilde{y}_t \tag{17}$$

where $DT_t^* = 1(t > T_b)(t - T_b)$

$$\tilde{y}_t \quad \alpha \tilde{y}_{t\ 1} \underset{i\ 1}{\overset{k}{f}} c_i \ni \tilde{y}_{t\ i} \quad e_t \tag{18}$$

The Innovational Outlier models represent the change that is occurring gradually whereas Additive Outlier model represents the change that is occurring rapidly. All the models considered above report their asymptotic critical values.

More recently, additional test methods have been proposed for unit root test allowing for multiple structural breaks in the data series (Lumsdaine and Papell, 1997. Bai and Perron, 2003) which we are not going to discuss here.

Power of the Tests

Regarding the power of tests, the Perron and Vogelsang (1992) model is robust. The testing power of Perron (1997) models and Zivot and Andrews models (1992) are almost the same. On the other hand, Perron (1997) model is more comprehensive than Zivot and Andrews (1992) model as the former includes both t and DT_b while the latter includes t only.

3. A General-to-Specific-Search Procedure

Given the complexities associated with testing unit roots among a plethora of competing models, there is a need for a general to specific testing procedure to determine the stationarity of a time series in the presence of structural break.

Various models are suggested for the time series with intercept only, with trend only, and with both. Similarly, different models are prescribed for the time series with structural break and with time trend. In such a case, the researcher has to apply certain judgement based on economic theory in order to make assumptions about the nature of the time series. But such assumptions may not be always true and may lead to misspecification and totally wrong inferences. For these reasons, one faces the problem of selecting an appropriate method of unit root test.

Economic fundamentals and available information cannot be ignored while using the results given by a particular test method. For the results to be consistent with economic theory, different type of test methods or models may be appropriate for different time series. In such a case, sticking to only one method for all the time series could be inappropriate. This is more so if one is dealing with a large number of variables.

Against this backdrop, the following sequential procedure is proposed in order to select an optimal method and model of the unit root test.

Stage 1. Run Perron (1997): Innovational Outlier Model (*IO2*)
As mentioned earlier, this model includes t (time trend) and DT_b (time of structural break), and both intercept (DU) and slope (DT).
Check t and DT_b statistics
If both t and DT_b are significant, check DU and DT statistics
If both DU and DT are significant, select this model
If only DU is significant, go to Perron (1997): *IO1* model.
This model includes t (time trend) and DT_b (time of structural break), and DU (intercept) only.

If only DT is significant, go to Perron (1997): Additive Outlier model (AO)

This model includes t (time trend) and DT_b *(time of structural break), and slope (DT) only.*

In some cases, t and DT_b may be insignificant in IO2 but significant in IO1 or AO. Therefore, IO1 and AO tests should be conducted after IO2 in order to check the existence of such a condition.

Stage 2. If only t is significant in Stage 1, go to Zivot and Andrews (1992) models:

Zivot and Andrews (1992) models include t but exclude DT_b. Run Zivot and Andrews test with intercept, trend, and both separately and compare the results. Select the model that gives the results consistent with the economic fundamentals and the available information.

Stage 3. If only DT_b is significant in Stage 1, go to Perron and Vogelsang (1992) models:

Perron and Vogelsang (1992) models include DT_b *but exclude t.* Run IOM and AOM. Compare the statistics and select the appropriate model.

Stage 4. If both t and DT_b are not significant in Stage 1, this implies that there is no statistically significant time trend and/or structural break in the time series. In such a case, certain judgement is to be used to select the test method.

The rational behind employing the above sequential procedure is that the inclusion of irrelevant information and the exclusion of relevant information may lead to misspecification of the model. For example, the Perron 1997 – IO2 model includes t, DT_b, DU and DT. If the test results of a time series show that the DT is not relevant or significant, then using this model (IO2) for that time series involves the risk of the misspecification, because the irrelevant information (DT) is included in the model. In this case, the model that includes t, DT_b and DU, but excludes DT should be preferred. This means that Perron 1997-IO1 model may be appropriate for this time series. If in a model t, DT_b, DU and DT are significant, then using the Perron 1997 – IO1 model will be inappropriate and will lead to misspecification since Perron 1997 – IO1 model excludes DT.

4. Unit Root Test: A Walk-through Example

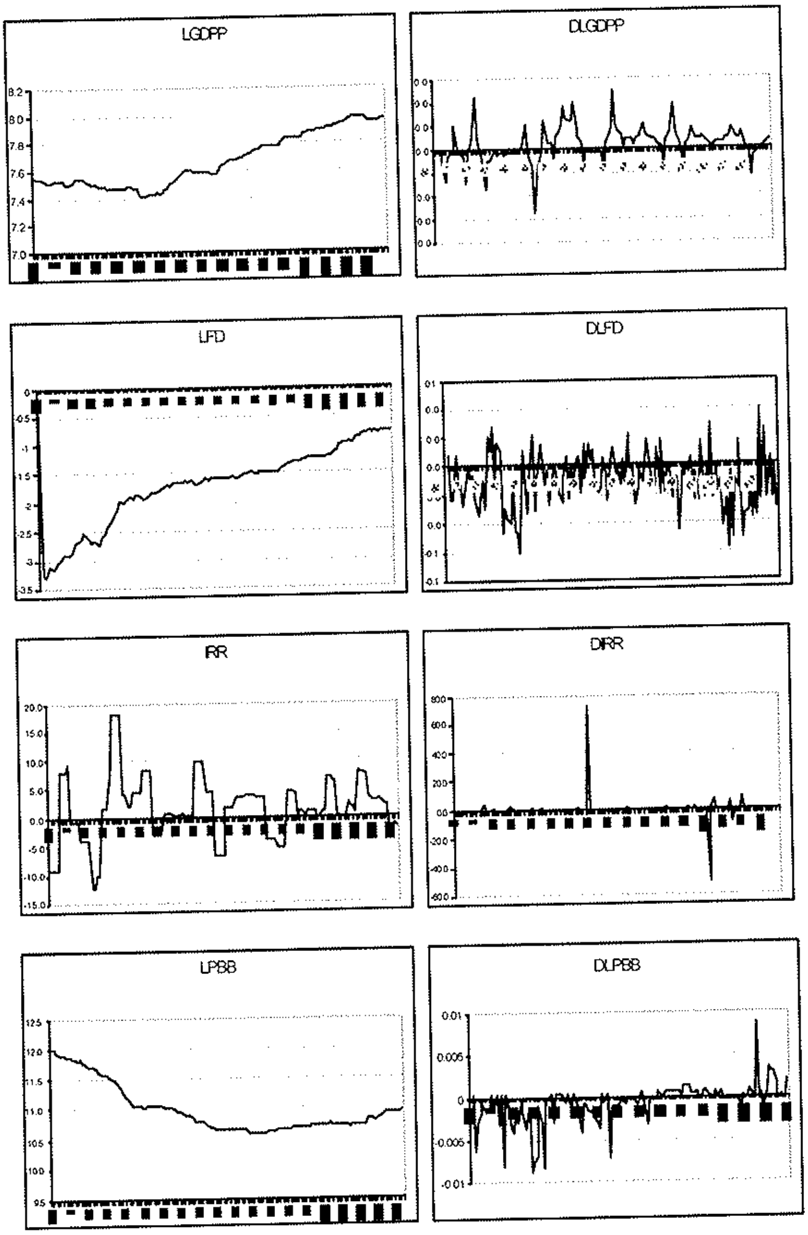
To illustrate the case, Nepalese quarterly data on four different economic variables have been used in this paper. Following Demetriades and Luintel (1996, p.304; 1997, pp.313-314), we develop the following equation, which is used to test the well-known financial liberalisation hypothesis for the Nepalese economy:

$$LGDPP_t \quad \beta_0 \quad \beta_1 LFD_t \quad \beta_2 IRR_t \quad \beta_3 LPBB_t \quad e_t \tag{19}$$

The economic time series include the log of real per capita GDP (LGDPP), the log of financial depth (LFD) proxied by bank deposits to GDP ratio, real interest rate (IRR) proxied by one year bank savings rate, and the log of average population density per bank branch (LPBB). IRR is measured in levels. The data covers a period of 34 years (136 quarterly observations) starting from 1970 quarter 1 and ending in 2003 quarter 4. The sources of the data include various issues of Economic Survey published by His Majesty's Government of Nepal, Ministry of Finance, and Quarterly Economic Bulletin published by Nepal Rastra Bank (the central bank of Nepal).

The data of these economic time series are plotted in the graphs at level as well as at first difference below. These graphs suggest that LGDPP, LFD, and LPBB are non-stationary time series and become stationary in the first difference, i.e., DLGDP, DLFD, and DLPBB, respectively. However, IRR seems to be stationary at level itself.

Graphs of the Time Series



The summary test statistics given by various unit root test models using RATS programme are presented in Tables 1 to 7 below[5]. The results are compared in Table 8 and a list of selected models for each time series and their results are presented in Table 9.

Table 1. Perron (1997) - IO2 Model Results

Variables	Tb	k	t	DT_b	DU	DT	T_α 1		Result
LGDPP	1978:4	12	**	**		**	-5.2232	*	Stationary
LFD	1975:2	11	**			**	-6.4034	*	Stationary
IRR	1979:3	11					-5.6118	*	Stationary ?
LBPP	1976:1	11					-3.2706		Non-stationary

Critical value for T_α 1 at 5% is -5.08 (Perron 1997, p.362).

* Significant at 5% level.** Coefficient close to zero and T-statistics significant at 5% level

The above unit root test statistics given by Perron (1997) - IO2 model shows that the set of all the four features of the time series (values for *t*, DT_b, *DU*, and *DT*) is individually significant for none of the series. From this, it can be inferred that this model is not appropriate for any of the time series.

Table 2. Perron (1997) - IO1 Model Results

Variables	Tb	k	t	DT_b	DU	T_α 1		Result
LGDPP	1973:4	12	**	**	**	-3.6742		Non-stationary
LFD	1975:2	11	**			-6.0374	*	Stationary
IRR	1975:2	11				-4.9801	*	Stationary
LPBB	1976:1	11	**		**	-3.3511		Non-stationary

Critical value for T_α 1 at 5% is -4.80 (Perron 1997, p.362).

* Significant at 5% level. ** Coefficient close to zero and T-statistics significant at 5% level

[5] The coefficients and their respective T-statistics of *t*, DT_b, *DU*, and *DT* are not reported in the table and are available on request.

Table 2 shows that all the three coefficients (t, DT_b, and DU) are individually significant for LGDPP but not individually significant for the other 3 time series. This implies that Perron (1997) – IO1 model is suitable only for LGDPP.

Table 3. Perron (1997) - AO Model Results

Variables	Tb	k	t	DT	T_{α} 1		Result
LGDPP	1978:2	9	**	**	-3.0888		Non-stationary
LFD	1973:1	10			-2.8347		Non-stationary
IRR	1975:2	11			-4.3553		Non-stationary
LPBB	1985:3	12	**	**	-3.4495		Non-stationary

Critical value for T_{α} 1 at 5% is -4.65 (Perron 1997, p.363)

* Significant at 5% level

** Coefficient close to zero and T-statistics significant at 5% level

The AO model statistics reported in the above table (Table 3) reveals that this model is relevant for LGDPP and LPBB but not relevant for LFD and IRR.

Table 4. Zivot and Andrews (1992) Model Results
(With both intercept and trend)

Variables	Tb	k	t	T_{α} 1		Result
LGDPP	1979:2	1	**	-4.3137		Non-stationary
LFD	1975:4	2		-5.4205	*	Stationary
IRR	1975:4	3		-7.1772	*	Stationary
LPBB	1999:1	0	**	-6.1178	*	Stationary

Critical value for T_{α} 1 at 5% is -5.08 (Zivot and Andrews 1992, p.257).

* Significant at 5% level ** Coefficient close to zero and T-statistics significant at 5% level

Table 5. Zivot and Andrews (1992) Model Results
(With intercept only)

Variables	Tb	k	t	T_{α}		Result
LGDPP	1987:2	1	**	-3.3413		Non-stationary
LFD	1975:4	2		-6.0289	*	Stationary
IRR	1975:4	3		-6.7627	*	Stationary
LPBB	1999:1	0	**	-6.1159	*	Stationary

Critical value for T_{α} at 5% is –4.80 (Zivot and Andrews 1992, p.256).* Significant at 5% level ** Coefficient close to zero and T-statistics significant at 5% level

Table 6. **Zivot and Andrews (1992) Model Results**
(With trend only)

Variables	Tb	k	t	T_{α}		Result
LGDPP	1980:2	1	**	-4.0649		Non-stationary
LFD	1977:3	2		-3.8214		Non-stationary
IRR	1976:2	3		-6.1314	*	Stationary
LPBB	1999:1	0	**	-6.0670	*	Stationary

Critical value for T_{α} at 5% is –4.42 (Zivot and Andrews 1992, p.256). * Significant at 5% level ** Coefficient close to zero and T-statistics significant at 5% level

The test statistics given by the Zivot and Andrews (1992) models are presented in Tables 4, 5, and 6. Three different models (namely, with both intercept and trend, with intercept only, and with trend only) return identical t values[6] and number of lags k. But the values for T_{α} are different for these three models. Regarding the date of structural break (T_b), all the three models give the same date for LPBB. Similarly, the break date given by first and second model for LFD and IRR are identical. The main issue of interest here is

[6] Not reported here, available on request.

stationarity of the time series and these models agree in the case of three time series only, namely, LGDPP, IRR and LPBB.

Table 7. Perron and Vogelsang (1992) Model Results (Innovational Outlier Model)

Variables	Tb	k	DT_b	DU	$T_\alpha = 1$		Result
LGDPP	1983 01	12		**	-2.3527		Non-stationary
LFD	1997 01	11		**	-3.6876		Non-stationary
IRR	1974 03	11			-4.6947	*	Stationary
LPBB	1975 02	12			-3.7036		Non-stationary

Critical value for T_α at 5% is -4.19 (Perron and Vogelsang 1992, p.308)

* Significant at 5% level ** Coefficient close to zero and T statistics significant at 5% level

As mentioned earlier, the Perron and Vogelsang (1992) model includes DT_b. In the above table (Table 7), DT_b is found to be statistically significant for none of the time series while DU is significant for LGDPP and LFD.

Table 8. Unit Root Test Result Comparison

	Perron 1997			Zivot-Andrews 1992			Perron-Vogelsang 1992	
Variables	IO2	IO1	AO	Both	Intercept	Trend	IOM	Result
LGDPP	S	N*	N*	N*	N*	N*	N	N*
LFD	S	S	N	S	S	N	N	?
IRR	S	S	N	S	S	S	S	?
LPBB	N	N	N*	S*	S*	S*	N	N*

N = Non-stationary, S = Stationary. * Significant (All the given features, i.e., t, DT_b, DU, and DT, whichever relevant, have coefficient close to zero and T-statistics significant at 5% level)

The results given by various models are summarised in Table 8 above. It can be seen from the table that Perron (1997) AO and Zivot and Andrews (1992) models are the best models for the series LGDPP and LPBB; and Perron (1997) IO1 model best fit for LGDPP. But there is no such match for the remaining two series, on the basis of a sequential search procedure produces better results. The above procedure can be extended by including the options for higher order of integration, i.e., *I(2)* and above, and for multiple structural breaks (more than one unknown breaks).

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